ESTIMATION OF SURFACE AREA OF COTTON PLANTS

by

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STATEMENT BY AUTHOR

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ABSTRACT

Regression equations were developed for prediction of total plant area and total leaf area of three varieties of cotton plants using plant height as the independent variable. The surface areas of Hopicala, Deltapine Smoothleaf, and Pima S-2 cotton varieties may be estimated using the general regression equation:

$$\log \hat{Y} = a + b \log X$$

where: $\hat{Y}$ = value of the estimated area,
a = a determined intercept,
b = a determined regression coefficient,
and, X = value of the mean measured height.

INTRODUCTION

DeBach (1967) indicated that a knowledge of the searching ability of predators and parasites is a prime requisite for their use as effective controls of crop pests. This information coupled with a measurement of the total searching universe aids in providing effective biological control programs.

The searching capacity of several predators and parasites has been investigated. Fleschner (1950) found that Stethorus picipes Casey, Conwentzia hageni Banks, and Chrysopa californica Coquillet effectively searched areas of 5.34, 5.78, and 107.00 square inches, respectively, in one hour. Fye and Larsen (1969) indicated that searching efficiency of Trichogramma minutum (Riley) is directly influenced by the complexity of the searching universe. Under ideal laboratory conditions and utilizing pizza pan arenas, the wasps traveled mean distances of 33, 22, and 29 cm at 23, 27, and 34°C in one hour and parasitized 11.9, 7.4, and 11.9% of the host eggs, respectively. Utilizing three artificial cotton plants, each 77.5 cm high, the wasps effectively parasitized host eggs the full height of the "plant" at 29°C. The greatest parasitization occurred in the top 27.5 cm.

The surface measurement of cotton leaves has been previously attempted by Ashley, Doss, and Bennett (1963) utilizing length and width measurements of cotton leaves to estimate their surface area. Later, Grimes and Carter (1969) developed a linear rule for direct area estimates of cotton leaves using a functional log relationship:

$$\log \text{leaf area } (cm^2) = a + b \log \text{leaf length } (cm).$$

Wendt (1967) employed a correlation between leaf area and leaf length to estimate leaf surface area of cotton and other crops. Johnson (1967) reviewed some methods of estimating leaf surface areas of cotton which involved correlating various measurements of the leaf itself, i.e., length of the main vein, width of the leaf, and diagonal length of the leaf, with the area of the leaf.

Barker (1968) used two methods for determining surface area of conifer needles. One was based on a photoelectric principle in which light intercepted by the needle was measured by a photometer. The other method was based on length and width measurements of the needles with correction factors for the needle curvature which was determined by using a polar planimeter.

The purpose of this study was to determine the aerial surface of long and short staple cotton varieties throughout the growing season and correlate the area with plant height, an easily obtained parameter in practice.

METHODS AND MATERIALS

Nine hundred thirty-two cotton plants were collected from May 25 to September 4, 1968, from four different fields and dissected in the laboratory to permit measurements of the various plant parts. The leaf blades and fruit bracts were pressed and held for measurement by storing them in a dry attic. Two fields of Pima S-2 and one each of Hopicala and Deltapine Smoothleaf (DPSL) were sampled. One Pima S-2 field was located approximately 15 miles northwest of Tucson near Rillito on highway Interstate 10. The DPSL field was located along the east bank of the Santa Cruz River approximately eight miles northwest of Tucson. The other Pima S-2 field and the Hopicala field were about one mile apart in the Avra Valley, 25 miles west of Tucson. Final calculations of surface area were based on 281 DPSL, 196 Hopicala, and 440 Pima S-2 plants.

At least 25 plants from each field were cut at ground level at approximately 10 day intervals. The 25 plants were selected from 25 points in a row in each field, the points being selected by first pacing the entire length of the row in each field and then dividing that number by 25 to determine the paces between each point. Due to the large size of the fields, the sample rows were restricted to include only plants which had been planted the same day to assure uniformity. No row was sampled twice during the season.

Table I lists the plant parts measured, measurements taken, and the measurement devices. A photometer was used to measure the leaves and bracts. Figure 1 is a diagram of the photometer and its integral parts labeled. The light source was a bank of C7 lamps covered with two plates of diffusion glass. A light-tight box with an open bottom and containing two photocells was placed over the light source. One photocell was directed at a circle with a 15 cm diameter where each leaf or bract to be measured was placed. To assure that the cell was properly oriented, a frame was used to hold the box in the proper location. The glass that was not covered with the box was painted black to reduce reflective light. The other cell was aimed at the light source and it compensated for the changes in light intensity. Before measurements were taken, potentiometers were adjusted to give zero output at the null voltmeter. Periodical adjustment of the zero was necessary because of the temperature changes of the photocells. The change of the photocell output due to the light interception of the leaf or bract was read directly on a digital voltmeter.

Pieces of paper toweling with the same light transmission as pressed leaves and of known area, ranging from one square inch to 50 square inches, were used to calibrate the photometer. The area of each piece was plotted against the photometer reading for that piece of paper and linear regression analysis performed. The final equation was:

Table I. List of plant parts measured, measurements taken, and measurement devices.

Plant Part	Measurement Taken	Measurement Devices
Leaves & Bracts	Light interception with conversion by regression equation to square centimeters	Photometer
Petioles	Length, diameter at middle (used on leaf and fruit petioles)	Meter stick, Vernier Calipers
Stems	Length, diameter at top and bottom	Meter stick, Vernier Calipers
Branches	Length, diameter at top and bottom	Meter stick, Vernier Calipers
Squares & Bolls	Diameter at widest point, length to tip, length to base	Vernier Calipers
Blooms	Petal area determined by measuring 30 mature blooms from each field and determining mean area. This area was converted to Photometer reading for convenience of use with the computer.	K & E Polar Planimeter and Photometer conversion

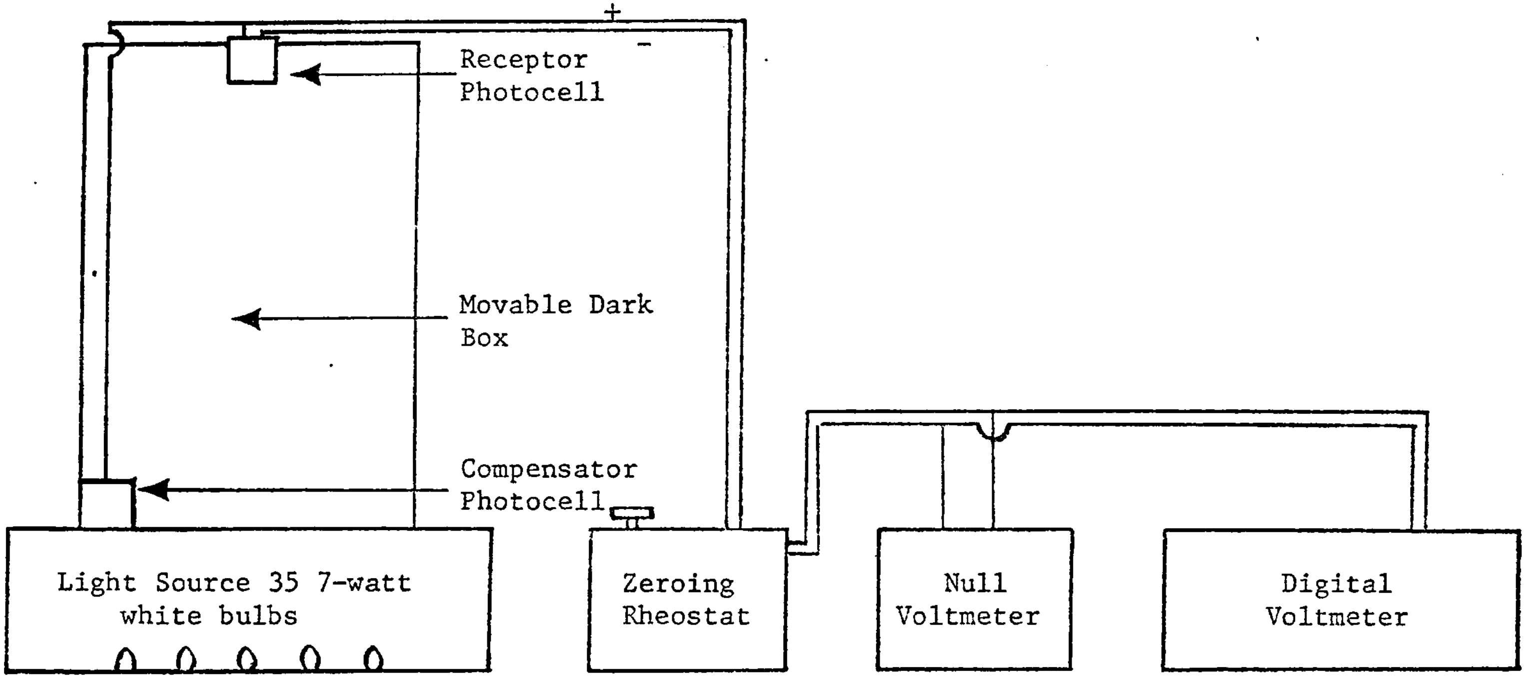

Figure 1. Diagram of photometer with integral parts labeled.

$$Y = \frac{-B + \sqrt{B^2 + 4AX}}{2A} \quad (6.45)$$

where: Y = area in sq cm,
A = 0.0037,
B = 0.079,
X = reading from digital voltmeter,
and, 6.45 = constant used to convert to cm^2.

Photometer readings from the leaves and bracts were recorded and converted to sq cm. During the conversion by the computer the area was multiplied by two to account for both sides of the leaves and bracts.

The calculations of the areas of the plant parts were made as follows:

1. Leaves and bracts. Photometer readings with Fortran program of regression equation for conversion to area.

2. Stems and branches using formula for frustrum of right cone.

$$\text{Area} = \pi \left[\frac{d_1}{2} + \frac{d_2}{2}\right] \sqrt{h^2 + \left[\frac{d_1}{2} - \frac{d_2}{2}\right]^2}$$

where: d_1 = diameter of top of stem or branch,
d_2 = diameter of bottom of stem or branch,
and, h = length of stem or branch.

3. Leaf and fruit petioles using formula for right cylinder.

$$\text{Area} = \pi \, dh$$

where: d = diameter at middle of petiole,
and, h = length of petiole.

4. Squares and bolls assuming the base to approximate a hemisphere and the tip to approximate a rotating ellipsoid.

$$\text{Area} = \frac{1.0472\,\frac{d}{2}\left[7h_1 + \frac{d}{2}\left(6 - \frac{\frac{d}{2}}{h_1}\right)\right] + \pi (h_2)^2}{2}$$

where: d = diameter at widest point,
h_1 = tip length from d,
and, h_2 = base length from d.

All plant parts were surveyed in profile to determine the best configuration. Petioles resembled right cylinders and measurements of diameter near the middle of the petiole yielded the best average diameter. Stems and branches resembled right cones, but the plants were divided into 15 cm increments. Therefore the formula for the frustrum of a right cone was used for both stems and branches to determine the surface area of each increment. The tip measurement was arbitrarily taken one cm below the tip. Using the frustrum of a right cone for both stems and branches simplified the computer programs for the calculations and gave excellent estimates of area.

Squares and bolls were first estimated volumetrically (water displacement in a graduated cylinder) and then several area to volume conversion formulae were applied to get the best estimate of area. The base of the fruit approximated a hemisphere while the tip of the fruit was regarded as a rotating ellipsoid.

RESULTS AND DISCUSSION

Tables II through V present the dates of samples, the number of plants in the samples used in data analysis, the mean height, mean total plant area, and mean total leaf area with their respective standard deviations for the plants from each of the four fields in the study. References to leaf and bract area include both upper and lower surfaces.

Linear regression analysis was performed by a CDC 6400® computer on the field data using height as the independent and area as the dependent variable after the data were transformed to common logarithms.

Table VI presents the regression analysis of log height with log area for total plant area and total leaf area for the plants from each field. Correlation coefficients for all values tested were highly significant (P = >> .01).

The values for leaf area in Table VI are for total leaf area and include leaf petiole area and leaf blade area. If area of leaf blade alone is desired the petiole area may be subtracted from the total leaf area. Petiole area of long staple cotton (Pima S-2) accounts for 7.1% of the total leaf area; the petiole area of short staple cotton (Hopicala and DPSL) accounts for 6.3% of the total leaf area.

Table II. Samples of Deltapine Smoothleaf with sample dates, number of plants used in data analysis, mean height, mean total area, and mean total leaf area with their respective standard deviation.

Date	Number of Plants	Height ± s.d. (cm)	Total area ± s.d. (cm^2)	Total leaf area ± s.d. (cm^2)
5-25	30	3.8 ± 0.9	23.2 ± 4.5	20.6 ± 4.5
5-31	25	5.2 ± 1.5	33.7 ± 9.7	30.3 ± 9.0
6-10	25	7.3 ± 1.6	77.8 ± 39.8	72.0 ± 38.1
6-17	25	7.1 ± 2.4	66.2 ± 24.8	61.2 ± 23.1
6-24	25	12.4 ± 3.4	178.8 ± 56.9	164.0 ± 48.4
7-01	25	18.1 ± 5.6	522.5 ± 272.3	496.5 ± 259.4
7-08	25	22.3 ± 6.7	694.3 ± 255.8	649.7 ± 238.6
7-17	25	34.6 ± 11.3	1276.7 ± 722.5	1175.1 ± 670.6
7-25	26	48.7 ± 15.2	3235.6 ± 1795.8	2890.3 ± 1647.5
8-10	25	79.1 ± 11.7	6359.7 ± 2649.6	5405.3 ± 2252.3
9-03	25	97.5 ± 14.8	7950.6 ± 2872.5	6290.0 ± 2324.4

Table III. Samples of Pima S-2 with sample dates, number of plants used in data analysis, mean height, mean total area, and mean total leaf area with their respective standard deviation (plant-2-skip-1 planting pattern)

Date	Number of Plants	Height ± s.d. (cm)	Total plant area ± s.d. (cm^2)	Total leaf area ± s.d. (cm^2)
5-31	25	13.9 ± 18.5	375.7 ± 157.7	360.6 ± 154.0
6-10	25	19.2 ± 18.5	887.1 ± 232.7	847.6 ± 223.1
6-17	26	28.3 ± 32.6	1758.9 ± 657.3	1636.4 ± 564.5
6-24	25	32.0 ± 32.5	2368.9 ± 809.9	2228.6 ± 757.5
7-01	25	45.7 ± 66.0	3211.9 ± 1718.2	2963.6 ± 1661.7
7-17	25	63.9 ± 74.5	5141.8 ± 1788.2	4383.0 ± 1480.8
7-25	25	83.7 ± 59.0	9500.1 ± 2791.3	7303.6 ± 2325.1
8-10	25	112.1 ± 21.0	13041.8 ± 3701.9	10367.9 ± 2892.3
8-27	24	135.6 ± 13.7	15710.7 ± 3976.1	11836.7 ± 3080.1

Table IV. Samples of Hopicala with sample dates, number of plants used in data analysis, mean height, mean total plant area, and mean total leaf area with their respective standard deviation.

Date	Number of Plants	Height ± s.d. (cm)	Total area ± s.d. (cm^2)	Total leaf area ± s.d. (cm^2)
6-10	25	25.7 ± 6.0	694.4 ± 213.2	628.5 ± 192.9
6-17	25	34.6 ± 12.3	1667.0 ± 760.9	1476.5 ± 659.8
6-24	25	43.9 ± 8.8	2090.3 ± 994.4	1818.0 ± 859.8
7-01	25	57.9 ± 11.7	4035.5 ± 1585.9	3431.1 ± 1308.0
7-08	24	56.8 ± 19.5	4591.6 ± 2225.1	3081.2 ± 1756.3
7-18	25	96.7 ± 11.3	8579.0 ± 3067.4	6755.3 ± 2485.1
8-05	22	92.6 ± 13.5	13048.1 ± 3685.5	10400.8 ± 3068.5
8-22	25	141.3 ± 13.7	15877.9 ± 6971.0	13337.3 ± 5958.3

Table V. Samples of Pima S-2 with sample dates, number of plants used in data analysis, mean height, mean total plant area, and mean total leaf area with their respective standard deviation (solid-planted row pattern).

Date	Number of Plants	Height ± s.d. (cm)	Total area ± s.d. (cm^2)	Total leaf area ± s.d. (cm^2)
5-31	25	15.4 ± 3.0	470.5 ± 195.2	450.1 ± 186.8
6-10	23	20.2 ± 4.8	1143.4 ± 640.1	1082.6 ± 598.8
6-17	25	24.1 ± 6.5	1720.8 ± 968.3	1614.0 ± 909.9
6-24	25	35.0 ± 9.5	4178.0 ± 1743.4	3812.7 ± 1533.7
7-01	22	47.6 ± 12.2	5434.6 ± 2460.7	4841.8 ± 2171.1
7-08	25	47.7 ± 16.5	4947.5 ± 2823.7	4056.4 ± 2139.1
7-18	23	85.7 ± 9.1	13773.2 ± 4758.5	10464.1 ± 3823.0
8-05	23	93.6 ± 14.4	15733.8 ± 8458.3	12276.6 ± 6709.1
8-17	24	112.7 ± 18.6	14752.1 ± 5713.0	11160.0 ± 4515.9

Table VI. Regression analysis of log height with log area.

Variety	Intercept (a)	Regression Coefficient (b)	SE of Regression Coefficient	Correlation Coefficient (r)	Coefficient of Determination (r^2)	SE of Estimate
			TOTAL PLANT AREA			
Deltapine Smoothleaf	0.40507	1.75328	0.02509	0.96523*	0.93167	0.23292
Pima S-2[a]	1.06343	1.47013	0.03646	0.93647*	0.87698	0.18999
Hopicala	1.12455	1.39193	0.06752	0.82854*	0.68649	0.27229
Pima S-2[b]	0.96652	1.59870	0.04989	0.90972*	0.82760	0.22977
			TOTAL LEAF AREA			
Deltapine Smoothleaf	0.37362	1.71939	0.02863	0.96302*	0.92742	0.23596
Pima S-2[a]	1.12193	1.38107	0.03591	0.93091*	0.86661	0.18696
Hopicala	1.08818	1.35150	0.06730	0.82138*	0.67468	0.27167
Pima S-2[b]	1.03900	1.49561	0.04989	0.89901*	0.80823	0.22940

[a]Planting pattern - 2 rows, skip 1.

[b]Planting pattern - adjacent 40" rows.

*Significant at P = .01.

Cultural practices on the Hopicala and DPSL fields were appreciably different. Hopicala was grown under a well managed commercial program, while the DPSL was experimental. Hopicala was grown in a predominantly Gila loam and Gila clay loam soil, but the DPSL was grown in sandy soil. Weeds were common in the DPSL field, with Johnson grass, Sorghum halepense (L.) Pers. and pigweed, Amaranthus spp., as major pests. The Hopicala field had 80 units of nitrogen applied; however, the DPSL had none because yield was not a critical factor.

One field of Pima S-2 was planted in a plant-2-skip-1 row pattern, and all the rows were planted in the other Pima S-2 field. The skip-row cotton was precision planted and required no thinning; the solid-planted Pima S-2 was thinned with a mechanical blocker with six to eight inches between plants. The skip-row Pima S-2 had 27.5 units of nitrogen applied in each of the first two irrigations after planting. The other Pima S-2 field had no fertilizer, because it was planted on land which had not been previously cultivated. Weed controls were good in both fields.

Varying cultural conditions were studied in this experiment to determine if a linear correlation between area and height of cotton plants existed in spite of the variable agronomic practices. For the two species, Gossypium hirsutum L. and G. barbadense L. the cultural conditions apparently did not significantly influence the relationship between the surface area and height.

A demonstration of the entomological usage of these data may be derived from observations made in the Safford Valley, Arizona, in

1967. A Trichogramma sp. release program, utilizing a biparental strain from New Mexico was initiated in a field of short staple cotton about June 19, 1967. The egg parasites were released at a rate of 5,000/acre twice weekly through the middle of September as potential control of pink bollworm, Pectinophora gossypiella (Saunders). No insecticides were sprayed during the release period. On September 12 there was a 33% infestation of pink bollworms.

Utilizing the Hopicala regression equation from Table VI and sex ratios of 66:34 presented by Lund (1938) the potential area searched on June 19 may be calculated:

$$\text{Area searched} = \frac{\log 2626 \text{ cm}^2 - 1.12455}{1.39193} (6600 \text{ females})$$
$$= 52,520,000 \text{ cm}^2.$$

The number of female Trichogramma sp. was estimated to be 6,600 and the plant height 44 cm. Thus, June 19 is concurrent with June 24 in Table IV of Hopicala data. The calculations indicate that the releases could have provided effective parasitism at that time; however, within one week there was 1.9-fold increase in plant area, and in three weeks there was a four-fold increase. Eight weeks later, on August 22, there was a 7.6-fold increase in plant area from June 24. If the rate of application of 10,000 wasps per week was constant in the control program, there could have been a decreasing effectiveness due to the inability to completely search the increasing area.

Fye and Larsen (1969) indicate that for maximum efficiency of the parasite there must be fresh host eggs present at all times. Therefore, eggs 24 hours old and older have much less chance of being parasitized than freshly laid ones, and maintenance of a high density of parasites is necessary to insure peak parasitizm.

Calculation of the number of parasites needed on September 12 will demonstrate the possible shortage of actual numbers of Trichogramma sp. in the field.

Conservative estimates placed the average plant height at 130 cm. Therefore:

Area per plant = 1.12455 + 1.39193 (log 130 cm)
= 11,660 cm^2.
Area per acre = 20,000 plants per acre (common planting level in Arizona) x 11,660 cm^2
= 233,200,000 cm^2/acre (5.58 acres of plant surface per acre of planted ground).

Trichogramma sp. adults are able to survive for approximately five days at September temperatures occurring in the Safford Valley. Under ideal laboratory conditions and utilizing pizza pan arenas, the wasps effectively search a minimum of 44 cm^2 per hour (Fye and Larsen, 1969).

Area searched per female = 44 cm^2/hour x 120 hours
= 5280 cm^2 per adult per life.
Total # females needed = 233,200,000 ÷ 5280 cm^2 per adult per life
= 44,167 females.

If 66% of adults are females (Lund, 1938):

Total adults needed = 44,167 ÷ 0.66
= 66,919 adults.

These figures serve to demonstrate that the number of wasps commonly applied in the Trichogramma sp. release programs appear destined to fail simply because there is a lack of numbers of adult females.

The extreme variance associated with the mean areas of the cotton plants suggests the searching universe in the example may have been appreciably less, and the Trichogramma sp. release program might have failed for other reasons. Calculation of the standard error of the mean:

$$s_{\bar{x}} = \frac{s}{\sqrt{n}}$$

indicates the actual mean probably lies in a much narrower range. The standard error of the mean may be readily calculated from information in Tables II-V.

These data might enable entomologists to test biological control agents more effectively, and might also aid in determining proper distribution and quantities of pesticides.

Agronomists, plant physiologists, plant breeders, and others might use these data to plan basic plant research more effectively by having a better understanding of the relationships among the various plant parts.

SUMMARY AND CONCLUSIONS

Biological control with mobile predators or parasites can best be accomplished if their searching capability is known and the area to be searched can be determined.

Measured heights of cotton plants will give adequate estimates of total plant area or total leaf area by utilizing the simple linear regression equation:

$$\log \hat{Y} = a + b \log X,$$

where: $\hat{Y}$ = log of the estimated area,
a = a determined intercept,
b = a determined regression coefficient,
and, X = log value of the mean measured height.

REFERENCES

Ashley, D. A., B. D. Doss, and O. L. Bennett. 1963. A method of determining leaf area in cotton. Agron. J. 55:584-5.

Barker, H. 1968. Methods of measuring leaf surface area of some conifers. Forestry Branch Dep't. Pub. #1219. Canadian Forestry, 6 pp.

DeBach, Paul. 1967. Biological control of insect pests and weeds. Reinhold Publ. Co., 844 pp.

Fleschner, C. A. 1950. Studies in searching capacity of the larvae of three predators of Citrus Red Mite. Hilgardia 20:233-65.

Fye, R. E. and D. J. Larsen. 1969. Preliminary considerations of Trichogramma minutum (Riley) for inundative biological control of Lepidopterous pests. J. Econ. Entom. 62(6):(in press).

Grimes, Donald W. and Lyle M. Carter. 1969. A linear rule for direct nondestructive leaf area measurements. Agron. J. 61(3):477-9.

Johnson, R. E. 1967. Comparison of methods for estimating cotton leaf area. Agron. J. 59:493-4.

Lund, H. O. 1938. Studies on longevity and productivity in Trichogramma evanescans. J. Ag. Res. 56:421-39.

Wendt, Charles W. 1967. Use of a relationship between leaf length and leaf area to estimate leaf area of cotton, castors, and sorghum. Agron. J. 59:484-6.